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CFD Analysis into the Resistance Interference of Displacement Trimaran

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ABSTRACT

Background: An investigation into the breakdown of resistance components of a displacement trimaran was carried out numerically using computational fluid dynamics (CFD) technique. **Objective:** A trimaran model consisting of one main-hull with length of 1.2m and two symmetric side-hulls with length of 0.5m was tested at various configuration between Froude numbers of 0.15 and 0.27 at various lateral spacings (S/L) between 0.2 and 0.5. The CFD investigation was conducted using a commercial code called ANSYS-CFX. Individual test on each part of trimaran hulls was also carried out in order to clarify the interference phenomena between the hulls more obviously. **Results:** Overall results indicate that CFD method demonstratesthat the wider the hull separation, the smaller the interference between the hulls, vice versa. Furthermore, the wider separation (S/L=0.5) indicates the likely no-interference between the hulls as the result is very close with individual test of each hull when interference is neglected. **Conclusion:** Comparative analysis with published data also supports the findings.

INTRODUCTION

The increase use of vessels for carrying cargoes and passengers in has widely grown up since the last 40 years. Various hull form and configuration has been developed and these include the development of mono- and multi-hull types of vessel. Among those vessels, the use of multihulls (catamaran and trimaran) have received considerable attention attributed to its better transverse stability and providing wider deck area compared to the monohulls (Utama*et al*, 2012 dan Jamaluddin *et al*, 2013). Multihulls demonstrate unique resistance characteristics in a way to reduce the use of energy and in particular, in order to reduce the use of fossil fuels.

Several work had been carried outin the past such as done by Utama *et al* (2010) who did an investigation into the drag characteristics of catamaran fishing vessel experimentally and numerically, Sarles *et al* (2011) carried out a study into the section shape effect on the interference resistance of catamaran, and Murdijanto *et al* (2011) investigated the resistance, powering, and seakeeping characteristics of river catamaran and trimaran.

Trimaran itself is a type of vessels with 3 hulls and comprises of one main-hull placed inside and two side-hulls with (usually) lower length compared to the main-hull. Several work indicated that trimaran can offer lower resistance at higher speeds compared to monohulls has been reported by Maynard *et al* (2008) and Murdijanto *et al* (2011).Further work on trimaran resistance was reported by Mamood and De-bo (2011), who did a study into the resistance calculation of trimaran hull-form using computational fluid dynamics.Later, Muscat-Fenech and La Rosa (2014) investigated the resistance of trimaran at various configurations of separation and draught.

The work into the improvement of hull-form, including trimaran, have been carried out intensively worlwide in order to increase the speed in one hand, and reduce the energy consumption in the other hand

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(Molland *et al*, 2014). Those work, in particular, explained that trimaran hull form has interesting phenomena, in term of resistance characteristics, compared to monohulls and even to catamarans. The resistance of trimaran, however, cannot be formulated yet, because the number of its configuration can be a hundreds. The current work is attempted to provide such detail information on trimaran resistance based on certain configuration of separation and the study is carried out using computational fluid dynamics approach.

Review Of Resistance Calculation:

Resistance of Monohull:

William Froude is known as the pioneer on the prediction of ship resistance using a model which is far smaller than the real ship (Date and Turnock, 1999). Froude (1872) described that the total ship resistance consists of frictional resistance and residuary resistance, which is dominated by wave resistance. Froude's expression is formulated as:

$$C_T = C_F + C_R \tag{1}$$

Where $C_T$is total resistance coefficient, $C_F$is frictional resistance coefficient, and $C_R$is residuary resistance coefficient.

The approach of William Froude was improved by Hughes (1954) and Granville (1956), which introduced the term of form factor in order to take into account three-dimensional effect of the ship hull form. The total resistance is later grouped into 3 (three) main components, namely (1) *frictional resistance*, which is a tangential force created as a reaction between the molecules of water and the skin hull of ship and later known as resistance of surface area with comparable area and length with the ship model, (2) formor pressure resistance arises because of the shape of object and depends on the longitudinal section of the body and part of its component is popularly known as form factor (1+k), and (3) wave resistance is a form of drag that affects surface watercraft, such as boats and ships, and reflects the energy required to push the water out of the way of the hull and this energy goes into creating the wave.

The description is formulated mathematically as:

$$C_T = (1 + k)C_F + C_W = C_V + C_W \tag{2}$$

Where $C_W$is wave resistance coefficient, (1+k) is form factor, and$(1+k)\ C_F$is viscous resistance coefficient which later expressed as $(1+C_V)$.

The value of$C_F$may be estimated using ITTC-1957 correlation line:

$$C_F = \frac{0.075}{(\log(\mathrm{Re}) - 2)^2} \tag{3}$$

Furthermore, international standard by ITTC-1978 (Molland *et al*, 2011) practically classified the total ship resistance into 2 (two) major components: viscous resistance as a function of Reynolds (Re) number and waveresistance as a function of Froude (Fr) number and the correlation between the 2 (two) components is formulated as:

$$R_{T(Fr,\ Re)} = R_{W(Fr)} + R_{V(Re)} = R_{W(Fr)} + (1+k)_{(Fr)}\ R_{F(Re)} \tag{4}$$

Later the resistance components are broken down into further details and including spray, wave breaking, transom drag, induced drag, etc (Couser *et al*, 1997) and shown in Figure 1.

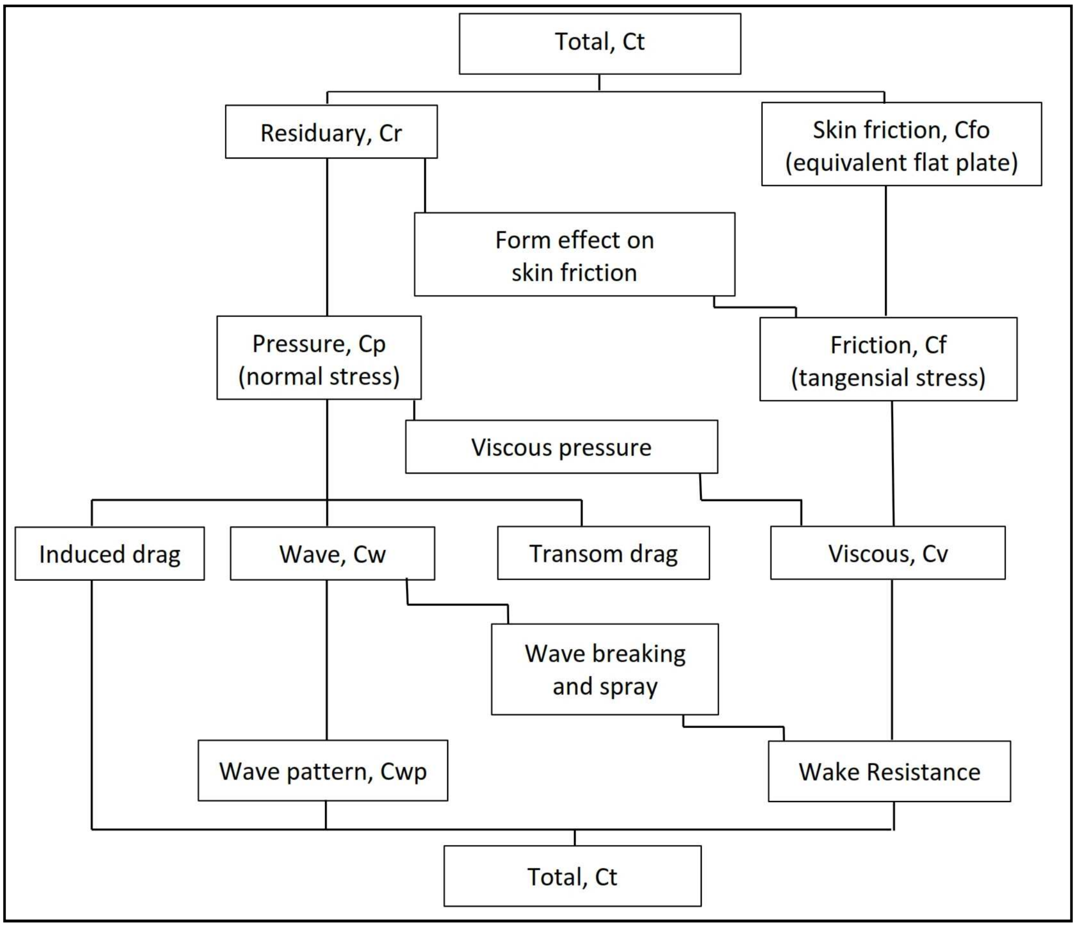

Fig. 1: Breakdown of resistance into its components (Couser *et al*, 1997)

Resistance of Trimaran:

Resistance of a trimaran can be calculated from the resistance of each individual hull (mainhull and sidehulls). However, when the three hulls are combined together and forming a trimaran, its total resistance is higher than the summation of individual resistance. The difference is attributed to resistance interference or interaction. Certain formulation to calculate the total resistance and its interference is not avaiable yet, but simple expression by Pien (1976) and Jamaluddin (2012) may be used and formulated as:

$$IF = \frac{R_{T2}}{R_{T1}} \tag{5}$$

Where IF is interference factor, R_{T2} is total resistance of trimaran configuration, and R_{T1} is total resistance of individual hull forming a catamaran.

Material And Methodology:

The investigation was conducted numericallyusing CFD approach and a commercial CFD code called ANSYS CFX was applied. The body plan of ship was shown in Figure 2 showing main-hull and side-hull, whilst the position of main-hull and side-hull in trimaran configuration was shown in Figure 3. Furthermore, principal particulars of ship together with the trimaran configuration and variation of test were given in Tables 1 and 2, respectively.

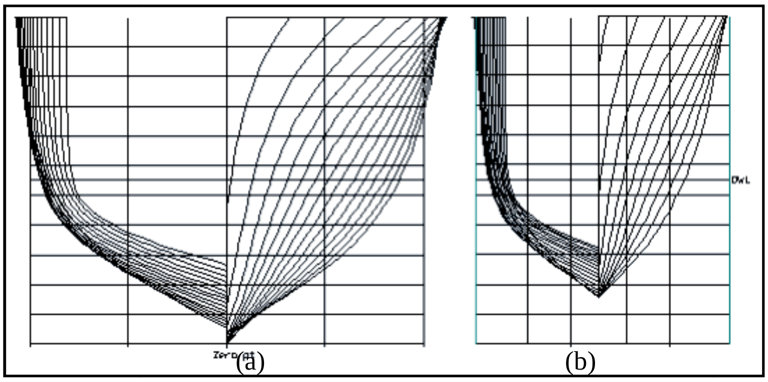

Fig.2: Body plan of model: mainhull (a) and sidehull (b)

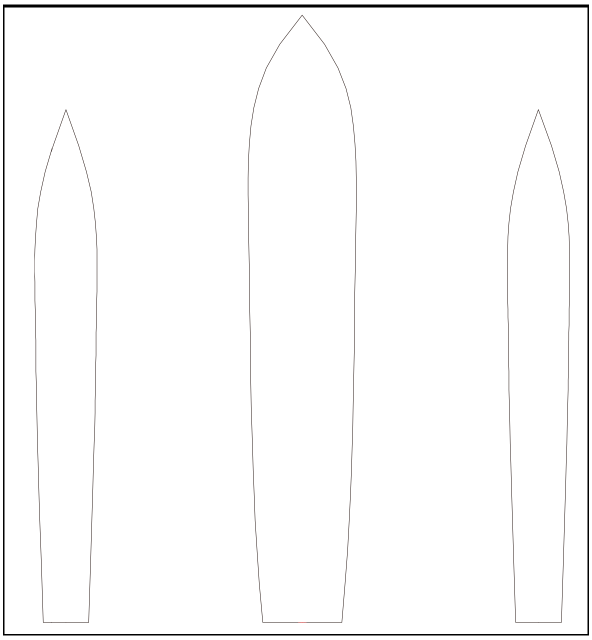

Fig. 3: Trimaran configuration

Table 1: Principle particulars of trimaran vessel

Particular		Trimaran vessel
LOA	m	74.14
LPP	m	72.09
$LOA_{Sidehull}$	m	62.639
$LPP_{Sidehull}$	m	60.177
$B_{Mainhull}$	m	9.91
$B_{Sidehull}$	m	5.71
B (S/L = 0.2)	m	34.55
B (S/L = 0.3)	m	48.98
B (S/L = 0.4)	m	63.38
B (S/L = 0.5)	m	77.94
H	m	7.16
T	m	3.951
WSA	m^2	1367.93
Displacement	ton	1440.00

Table 2: Configuration and Various Speed of Test

Froude Numbers (Fr)	Clearance (S/L)
0.15, 0.17, 0.19, 0.21, 0.23, 0.25, 0.27	0.2, 0.3, 0.4, 0.5

CFD Analysis:

Computational Fluid Dynamics (CFD) technique, of a varying degree of complexity, may be used to predict the fluid flow problems such as resistance components (Jamaluddin, 2012) and the performance of CNG engine (Balaji and Selvakumar, 2016). In term of ship resistance, in particular, potential code may be applied to derive the pressure resistance due to inviscid flow characteristics (wave pattern resistance). The boundary layer intergral method may be used to estimate the boundary layer growth in areas where separation and circulation do not occur. The method would provide some insight into the pressure form drag. Full Reynolds-Averaged Navier-Stokes (RANS) codes may be used to predict the flow where separation and circulation occur, thus potentially providing good estimates of form factor and possible scale effect; however these methods are extremelly computationally intensive, particularly for the computation of high Reynolds number flow.

CFD is presently being widely used as these advanced technologies take advantage of the increasing speed of computers. CFD is defined as a technique for making hydrodynamic calculations to predict the basic phenomenaof specific flow problems (Morgan and Lin, 1987). CFD may also be explained as an analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer based simulation (Versteeg and Malalasekera, 2007). The technique is very powerful and spans a wide range of industrial and non-industrial application areas. These include mixing and separationin chemical process engineering, flows inside rotating passages in turbo-machinery, calculation of lift and drag in aerodynamics of aircraft and vehicles and hydrodynamics of ships. In the past decade, many efforts have been devoted to the development of mathematical models for CFD and the capabilities ofthe models in predicting equipment fluid dynamics have often been assessed through the comparison with experimental data (Sasikumar and Vijayakumar, 2015).

CFD analysis was carried out in order to figure out the flow movement phenomenon thus contributes to the decrease of total resistance. Several work on the resistance investigation have been done such as reported by Utama (1999), Utama and Molland (2001), Subramanian *et al* (2006), Siqueira *et al* (2007), Deng *et al* (2010), and Jamaluddin *et al* (2012).

The boundary conditions are set as follows as suggested by Utama (1999) and Ahmed and Soares (2009). The inlet boundary, located at 1.5L upstream from the ship, is defined as a uniform flow with velocity equals the ship velocity. The outlet boundary, at a location of 4L downstream from the ship, is given as that the pressure equals the undisturbed pressure, ensuring no upstream propagation of disturbances. Furthermore, the distance with two sides of boundary is made 1.5L and distance with top and bottom boundaries is set 2.5L. The boundary condition at the hull surface is defined as no-slip boundary and at the (parallel to the flow direction) horizontal and vertical walls bounding the flow domain as free-slip boundary. Details of the desciption can be seen in Figure 4. The investigation was conducted without and with free surface effect in order to quantify the contribution of wave resistance to the total resistance.

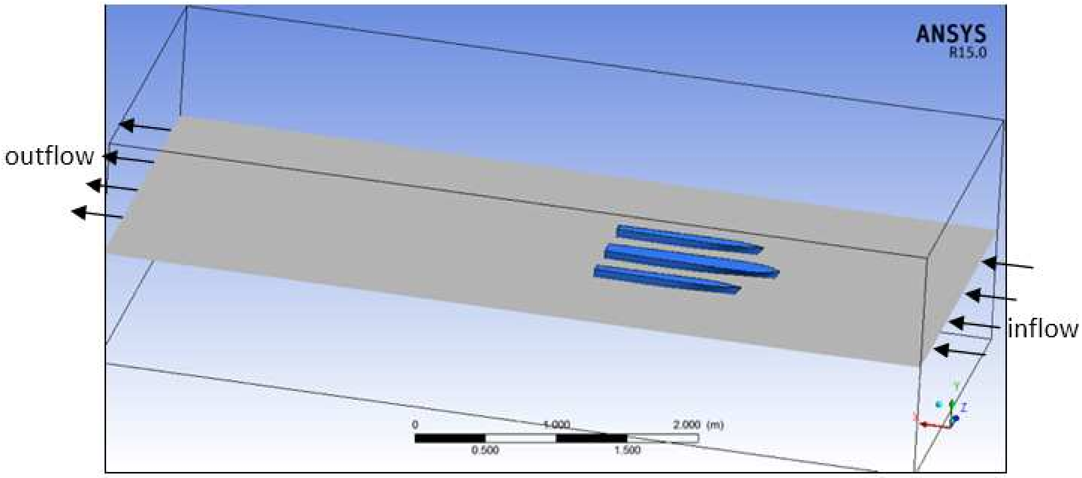

Fig. 4: Setting of model and boundary conditions in CFD domain

The Reynolds-averaged Navier–Stokes equations (or RANS equations) are time-averagedequations of motion for fluid flow. The idea behind the equations is Reynolds decomposition, whereby an instantaneous quantity is decomposed into its time-averaged and fluctuating quantities, an idea first proposed by Osborne Reynolds. The RANS equations are primarily used to describe turbulent flows. These equations can be used with approximations based on knowledge of the properties of flow turbulence to give approximate time-averaged solutions to the Navier–Stokes equations. For a stationary, incompressible Newtonian fluid, these equations can be written in the following notation (Equation 6):

$$\rho\bar{u}_j\frac{\partial \bar{u}_i}{\partial x_j} = \rho\bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right] \tag{6}$$

Among all turbulence model, the SST model was used. The SST two-equation turbulence model was introduced by Menter(1993 and 1994) to deal with the strong free-stream sensitivity of the k-omega turbulence model and improve the predictions of adverse pressure gradients. The formulation of the SST model is based on physical experiments and attempts to predict solutions to typical engineering problems and given in Equation (7). Over the last two decades the model has been altered to more accurately reflect certain flow conditions. The Reynolds Averaged Eddy-viscosity is a pseudo-force and not physically present in the system. The two variables calculated are usually interpreted thus k is the turbulence kinetic energy and omega is the rate of dissipation of the eddies. Furthermore, the SST model has been used and validated by several researchers including Bardina *et al* (1997), Swennberg (2000),and Mahmood and De-bo (2011) with successful results.

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=P-\beta^{*}\rho\omega k+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right] \tag{7}$$

RESULTS AND DISCUSSIONS

Grid independence and convergence criterion:

Grid independence study was carried out in order the total resistance to comply with the convergence and grid-independence criteria. The convergence criterion is 10^{-5}, based on momentum residual, as recommended by Dinham *et al* (2008). The criterion of grid independence is defined such that the difference between two subsequently calculated ship resistances, the latter calculation using a number of cells (elements) approximately twice of that used in the former, is less than 2% (Anderson, 1995). To illustrate this, Table 3 shows a summary of ship resistance calculations using different number of elements. In this case, using a number of elements of 1,582,580(or approximately 1.6 million) in the simulation satisfies the grid-independence criterion as stated above.

Table 3: Grid Independence Study

Number of grid	50,822	102,620	202,162	408,291	812,738	1,582,580	3,075,830
Resistance (N)	4.065	3.368	2.884	2.563	2.360	2.262	2.219
Percentage of Difference		20.684	16.793	12.546	8.581	4.332	1.938

Total, Viscous, and Wave Resistance Coefficients:

Likely the experimental investigation, the values of '1+k' within CFD analysis can be found by conducted a low speed test where C_W closes to zero hence $(1+k)=C_T/C_F$. In this case, the method of Prohaska (ITTC 1978, 2002; Bertram 2000) may be used:

$$C_T=(1+k)\,C_F+a\,Fr^n \tag{8}$$

It is assumed that $C_W = aFr^n$for low speed test (generally $Fr< 0.2$), and*form factor (1+k)* can be calculatedthrough *straight-line plot* betweenC_T/C_FandFr^4/C_Fcoincides at Fr=0, and the values of n = 4 – 6 and generally used as n=4 (Molland *et al*, 2011).

The results CFD investigation were summarised in Tables 4 to 6 and plotted in Figure 5 showing the magnitude of each resistance components at various speeds (Froude numbers) and separation to length ratio (S/L).

Table 4: Total resistance coefficient estimation

Fr	Total Resistance Coefficient				
	Trimaran Hull ($\times 10^{-3}$)	S/L = 0.2 ($\times 10^{-3}$)	S/L = 0.3 ($\times 10^{-3}$)	S/L = 0.4 ($\times 10^{-3}$)	S/L = 0.5 ($\times 10^{-3}$)
0.15	4.170	4.491	4.391	4.291	4.120
0.17	4.158	4.848	4.647	4.458	4.162
0.19	4.423	5.258	5.003	4.803	4.433
0.21	5.035	5.965	5.446	5.265	5.135
0.23	5.608	6.295	6.195	5.947	5.618
0.25	5.801	6.443	6.393	6.293	5.911
0.27	5.765	6.653	6.533	6.333	5.825

Table 5: Viscous resistance coefficient estimation

Fr	Viscous Resistance Coefficient				
	Trimaran Hull ($\times 10^{-3}$)	S/L = 0.2 ($\times 10^{-3}$)	S/L = 0.3 ($\times 10^{-3}$)	S/L = 0.4 ($\times 10^{-3}$)	S/L = 0.5 ($\times 10^{-3}$)
0.15	3.206	3.241	3.221	3.212	3.209
0.17	3.192	3.234	3.214	3.204	3.196

0.19	3.170	3.174	3.174	3.194	3.161
0.21	3.111	3.149	3.149	3.186	3.116
0.23	3.097	3.139	3.139	3.163	3.103
0.25	3.080	3.151	3.121	3.121	3.091
0.27	3.094	3.075	3.105	3.106	3.064

Table 6: Wave resistance coefficient estimation

Fr	Wave Resistance Coefficient				
	Trimaran Hull ($x\ 10^{-3}$)	S/L = 0.2 ($x\ 10^{-3}$)	S/L = 0.3 ($x\ 10^{-3}$)	S/L = 0.4 ($x\ 10^{-3}$)	S/L = 0.5 ($x\ 10^{-3}$)
0.15	0.964	1.251	1.170	1.080	0.911
0.17	0.966	1.614	1.433	1.254	0.966
0.19	1.253	2.085	1.829	1.609	1.272
0.21	1.924	2.816	2.297	2.079	2.019
0.23	2.510	3.156	3.056	2.784	2.514
0.25	2.720	3.291	3.272	3.172	2.820
0.27	2.671	3.578	3.428	3.227	2.761

It is apparent that as the spacing (S/L) increases, the resistance interference decreases and this is in good agreement with the work done by Insel and Molland (1992), Utama (1999), and Jamaluddin (2012). It was shown that the total, viscous and wave resistances at the highest spacing (S/L=0.5) is nearly the same as the total resistance of individual trimaran when the interference is not taken into consideration. It is an indication that the interference tends to be zero or unity at the widest spacing This fact agrees well with the work done by Couser *et al* (1997), Utama (1999), Utama and Molland (2001), and Jamaluddin (2012).

If searched more closely, it is apparent that the total resistance interference was about 2%, whilst the viscous resistance interference and wave resistance intereference were about 0.1% and 4%, respectively. It is an indication that wave resistance interference is more dominant than viscous resistance interference, which is tend to be zero or very small because the hull of catamaran is quite slender (L/B main-hull is about 7.5 and L/B side-hull is about 11). In addition, the interference tends to increase as the speed increases and this is attributed to more intensive (especially wave) interference, which is created at higher speeds.

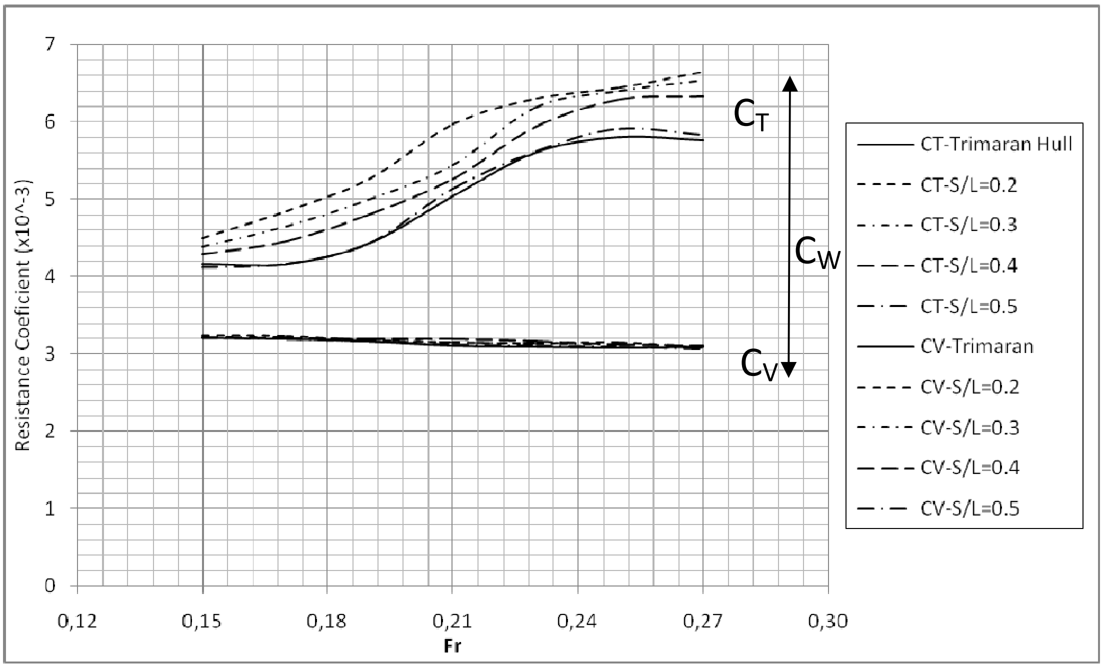

Fig. 6: Plotted of resistance coefficients of trimaran

Conclusions:

The current study has demonstrated the use of CFDmethod into the breakdown and analysis of trimaran resistance quite successfully. It is obvious that the resistance interference decreases as the spacing or separation between the hull increases. The resistance interference is dominated by wave resistance interference (and not by viscous resistance interference). This is due to the slenderness of the hull in one hand, and the creation of more excessive wave (and hence the wave interference) at higher speeds. The wave resistance interference contributed about 4% effect on the total resistance, whilst the viscous resistance interference is only about 0.1%.

The overall results showed that the widest separation can give almost the same resistance and hence power requirement. This is a good indication that trimaran configuration can give lower resistance than monohull of similar displacement in order to reduce the use of fossil fuels and the effect of toxic gases into the atmosphere.

REFERENCES

Ahmed, Y.,C.G.danSoares, 2009. “Simulation of Free Surface Flow around a VLCC Hull Using Viscous and Potential Flow Methods”, *Ocean Engineering*, 36: 691-696.

Anderson, J.D. Jr., 1995.Computational Fluid Dynamic.McGraw-Hill. New York.

Balaji,B.and M. Selvakumar, 2016. CFD Analysis of Injection Mixer for CNG Engines for Optimized Performance, Aust.J. Basic & Appl. Sci., 10(1): 368-374.

Bardina, J.E., P.G.Huangand T.J.Coakley, 1997. “Turbulence Modelling, Validation, Testing and Development”, *NASA Technical Memorandum* 110446

Bertram, V., 2000.*Practical Ship Hydrodynamics*, Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford OX2 8DP, UK., pp: 74.

Couser, P.R., A.F. Molland, N. Amstrong and I.K.A.P. Utama, 1997. Calm Water Powering Predictions for High Speed Catamarans, *Procs of FAST’97*, Sydney, Australia.

CFX, 2007. CFX Manual VII, Ansys.

Couser, P.R., 1996.*An Investigation into the Performance of High-SpeedCatamarans in Calm Water and Waves*, PhD Thesis, Department of ShipScience, University of Southampton, UK.

Couser, P.R., A.F. Molland, N. Armstrong and I.KA.P.Utama, 1997. “CalmWater Powering Predictions for High Speed Catamarans”, *Procs. of International Conference on Fast Sea Transportation*, FAST 1997,Sydney.

Date, J.C.andS.R.Turnock,1999. .*A study into the techniques needed to accurately predict skin friction using RANS solvers with validation against Froude's historical flat plate experimental data*. Southampton, UK, University of Southampton, pp: 62.

Deng, R., D. Huang, J.Li, X.Cheng, L.Yu, 2010. “Discussion of Grid Generation for Catamaran Resistance Calculation”, Journal of Marine Sci. Appl., 9: 187-191.

Dinham, T.A., C.Craddock, A.Lebas and A.Ganguly, 2008. *Use of CFD for Hull Form and Appendage Design Assessment on an Offshore Patrol Vessel and Identification of a Wake Focusing Effect*, RINA Marine CFD, Southampton, UK.

Granville, P.S., 1956. “The Viscous Resistance of Surface Vessels and the Skin Friction of Flat Plates”, *Trans SNAME* Vol. 64.

Insel, M.,A.F.dan Molland, 1992. “An Investigation into the Resistance Components of High Speed Displacement Catamarans”, *Trans RINA* 134.

ITTC-1978 2002.*Recommended Procedures and Guidelines, Testing and Extrapolation Methodsin Resistance Towing Tank Tests*, ITTC 7,5-02-02-02.

Jamaludin, A., I.K.A.P. Utama, W.D. Aryawan and B.Widodo, 2012. Experimental Investigations into the Resistance Components of Symmetrical Catamarans with Variations in Hull Clearances and Staggers, *RINA Transactions*, 154, Part B1.

Larsson, L. and E.Baba, 1996. Ship Resistance and Flow Computations. Advances in Marine Hydrodynamics, 5: 1-75, Computational Mechanics Publications, Southampton, Boston

Lin, W.H.,G.W.dan Morgan, 1987. Response of a Circular Rod to anAxial Turbulent Flow. in Flow-Induced Vibration-1987. (eds M.K. Au-Yang and S.S.Chen), 122: 81-86. ASME:New York

De Marco Muscat-Fenech, M., M.Claire, Grech La Rosa, Andrea, 2014. Resistance Analysis for a Trimaran, World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8: 1.

Menter, F.R., 1993. Zona Two Equation k-ω Turbulence Models for Fows, AIAA pp: 93-2906

Menter, F.R., 1994. “Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications”, AIAA Journal, 32: 289-289.

Molland, A.F., S.R.Turnock, D.A.Hudson and I.K.A.P.Utama, 2014. Reducing ship emissions: a review of potential practical improvements in the propulsive efficiency of future ships. Transactions of Royal Institution of Naval Architects Part A, 156: 175-188.

Mynard, T., K.Sahoo, Prasanta, Mikkelsen, Jon, McGreer, Dan, 2008. Numerical and Experimental Study of Wave Resistance for Trimaran Hull Forms, Launceston, TAS 7250, Australia

Miyazawa, M., 1979. “A Study on the Flow around a Catamaran”, *Journal of Society of Naval Architects of Japan*, 145: 49-56.

Molland, A.F., S.R.Turnock, D.A.dan Hudson, 2011.*Ship Resistance and Propulsion: Practical Estimation of Ship Propulsive Power*, Cambridge University Press, New York, USA.

Murdijanto, Utama, IKAP and A.Jamaludin, 2011. An Investigation into the Resistance/Powering and Seakeeping Characteristics of River Catamaran and Trimaran, Makara Seri Teknologi, 15: 1.

Mynard, T., Sahoo, K.Prasanta, Mikkelsen, Jon, McGreer, Dan, 2008. Numerical and Experimental Study of Wave Resistance for Trimaran Hull Forms, Launceston, TAS 7250, Australia

Pei-young, 2002. Research on Wave Loads of the Trimaran Cross Structure based on Three Dimensional Hydrodynamic Analysis. Research of Conceptual Design for Fast Trimaran. Journal of Shanghai Jiaotong University.

Pien, P.C.,1976.*Catamaran Hull-Form Design*, Proceedings of the International Seminar on Wave Resistance, the Society of Naval Architects of Japan (SNAJ)

Sahoo, P.K., M. Salas, A.dan Schwetz, 2007.*Practical Evaluation of Resistance of High Speed Catamaran Hull Forms – Part I*, Proc. of the Journal of Ships and Offshore Structures, 2(4): 307-324.

Sasikumar. R and Dr. KCK .Vijayakumar, 2015. Effect Of V-Shaped Impellers In The Shaft Co-Axial and Accentricity Position On Hydrodynamics Of Un Baffled Stirred Tank. Aust. J. Basic & Appl. Sci., 9(36): 583-591.

Siqueira, C.L.R., N.Spogis, R.Damian, M.Reis, 2007.*Overview of CFD Modeling for Ship Hull Interactions with Waves and Propellers*, 3 International Workshop on applied Offshore Hydrodynamics, Brazil, 17-19.

Swennberg, S.U., 2000.*A Test of Turbulence Models for Steady Flows Around Ships*, Gothenburg. Proc. Gothenburg, Workshop on Num. Ship Hydrodynamic

Turner, H. andA.Taplin, 1968.*The Resistance of Large Powered Catamaran*, Trans. SNAME, 76.

Utama, I.K.A.P., 1999.*Investigation of the Viscous Resistance Components of Catamaran Forms*, PhD Thesis, Department of Ship Science, University of Southampton, UK.

Utama, I.K.A.P., A.F.dan Molland, 2001. *Experimental and Numerical Investigations into Catamaran Viscous Resistance*, FAST'2001, Southampton, UK.

Utama, IKAP., 2008. An Investigation into the Resistance Characteristics of Staggered and Un-staggered Catamaran, RIVET, Kuala Lumpur – Malaysia.

Versteeg, H.K., and W.Malalasekera,1995. An Introduction to Computational Fluid Dynamics, Longman Scientific & Technical, England.

Froude, W., 1872.On the Influence of Resistance upon the Rolling of Ship. NavalScience. (p.155 in collected works).